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Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems

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ABSTRACT

Farmers in many Asian countries are moving from puddled-transplanted rice to dry-seeded rice systems. Dry-seeded rice can be sown after land preparation or under zero-till conditions. Weeds, however, are the major constraint to the production of dry-seeded rice. A study was conducted during the wet season of 2011 and dry season of 2012 at the farm of the International Rice Research Institute to evaluate the effect of tillage systems (zero-till and conventional tillage) and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. In the zero-till system, the densities of *Digitaria ciliaris*, *Eleusine indica*, *Eclipta prostrata*, and *Ludwigia octovalvis* increased many-fold from the first season to the second. The efficacy of herbicides (oxadiazon followed by fenoxaprop + ethoxysulfuron and oxadiazon followed by penoxsulam + cyhalofop) was lower in the zero-till system than in the conventional tillage system. Grain yield in the herbicide-treated and weed-free plots was similar between the tillage systems and this response was consistent during both the seasons. However, grain yield in the zero-till-control (one hand-weeded) plots was lower (0.9–1.5 t ha^{-1}) than in the conventional tillage-control plots. The information gained from this study suggests that yields in zero-till systems similar to those in conventional-tilled systems can be achieved if weeds are effectively controlled. In the absence of effective weed control, zero-till systems may result in poor grain yield.

1. Introduction

Rice is a principal source of food for more than half of the world's population. More than 90% of this rice is grown and consumed in Asia. There it is commonly grown by manual transplanting of 3–6-week-old seedlings in puddled soils, resulting from intensive cultivation in wet soil conditions. Puddling creates a hard pan below the plow layer, leads to high water losses through surface evaporation, and influences soil health because of the dispersion of soil particles and compacting soil (Singh et al., 2008; Chauhan, 2012; Chauhan et al., 2012a). Puddling and transplanting operations require a huge amount of water and labor. In the future, many rice farmers in Asia may have limited access to irrigation water. Around one decade ago, it was predicted that, by 2025, 13 Mha of irrigated wetland rice in Asia may experience physical water scarcity and 22 Mha of irrigated dry-season rice may suffer from economic water scarcity (Tuong and Bouman, 2003). In addition, there is also a concern about labor shortage because of the increasing wage resulting from the migration of rural labor to the cities (Pandey and Velasco, 2005; Chauhan, 2012). It is difficult for farmers to acquire labor at the critical time of seedling transplanting. These studies indicate that there is a need to evaluate alternatives to puddled-transplanted rice before water and labor scarcities become more critical.

In recent years, manual transplanting of rice in some Asian countries has been, or is being, replaced by dry-seeded rice as farmers respond to the decreased availability of labor or water or their increased costs (Pandey and Velasco, 2005). Dry-seeded rice crop has several advantages over transplanting rice. They are conducive to mechanization, are more rapidly and easily planted, are less labor intensive, use less water, and have fewer methane emissions (Farooq et al., 2011; Chauhan, 2012; Chauhan et al., 2012b). In dry-seeded systems, dry rice seeds are sown under zero-till (ZT) conditions or after tillage in a well-prepared seedbed. In addition to reducing labor and fuel costs, ZT systems may improve soil physical and chemical properties, conserve soil moisture, and reduce soil erosion (Triplett and VanDoren, 1977; Chauhan et al., 2007). Weeds, however, are the main constraint to the production of dry-seeded rice (Chauhan and Johnson, 2010; Chauhan, 2012; Chauhan et al., 2012a,b). The main reasons for the weed problem in dry-seeded rice systems are the absence of standing water at crop emergence to suppress weeds and the absence of a seedling size advantage between rice and weed seedlings as both emerge simultaneously in these production systems.

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Different tillage systems influence vertical weed seed distribution differently in the soil and this distribution of weed seed may influence the relative abundance of weed species in the field (Froud-Williams et al., 1981; Chauhan et al., 2006c; Chauhan and Johnson, 2009b). ZT systems, for example, leave most of the weed seeds near the soil surface after planting. The conditions for germination are favorable for weed seeds present on the soil surface. On the other hand, weed seeds present on the soil surface under ZT systems are prone to rapid desiccation and seed predation. With conventional tillage (CONT) systems, however, weed seedling emergence depends on the effect the tillage has on weed seed burial as seed buried too deep may not be able to emerge in these tillage systems. In a previous study in rainfed rice, seedling emergence of *Ageratum conyzoides*, *Digitaria ciliaris*, *Echinochloa colona*, *Eclipta prostrata*, *Eleusine indica*, and *Portulaca oleracea* was greater in a ZT system than in a CONT system (Chauhan and Johnson, 2009b); however, an artificial weed seed bank was used in this study. Information on the influence of tillage systems on the emergence pattern of different weeds from a natural seed bank is limited in the literature.

Weeding in Asia is commonly done by labor; however, this is becoming less common because of the non-availability of labor at the critical time of weeding and high labor costs. In the absence of manual weeding, herbicides are widely used to control weeds in dry-seeded rice systems. The use of a single herbicide does not give effective weed control and may result in shifts in problematic weed species. The trend toward dry-seeded rice systems, either sown under ZT or after tillage, is likely to continue and herbicides are an important tool of weed management in these systems. Therefore, there is a need to evaluate the performance of different herbicides that can provide effective weed control under different tillage systems. The information gained from such studies would help in deciding on the best weed management options for these systems.

A study was conducted at the farm of the International Rice Research Institute to evaluate the influence of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems.

2. Materials and methods

2.1. Description of the experiment

A field study was conducted during the wet season of 2011 (WS11) and dry season of 2012 (DS12) at the Research Farm of the International Rice Research Institute, Los Baños, Philippines. The soil at the site had a pH of 6.5, sand of 29%, silt of 44%, and clay of 27%. The study had two tillage systems: CONT and ZT. Two pre-sowing cultivations to a depth of 10–15 cm were given to the CONT plots, while soil disturbance in the ZT plots was limited to the sowing operation only. The ZT plots were sprayed 3–4 days before crop sowing with glyphosphate at 0.75 kg a.e. ha^{-1}. The ZT crop was sown into anchored rice stubbles of 15–20-cm height and there was no loose residue in the field. Rice (variety Rc222) was dry-seeded at 50 kg ha^{-1} in both tillage systems with a combine drill fitted with knife-point openers. Rice was sown in rows 20 cm apart on July 1, 2011, and January 7, 2012. A complete fertilizer (14:14:14 of $N:P_2O_5:K_2O$) was drilled with the seed at 30 kg ha^{-1} for each nutrient. After crop emergence, N was applied as urea at 150 kg ha^{-1} in four split doses: 45 kg N ha^{-1} at 28 days after sowing (DAS), 30 kg N ha^{-1} at 42 DAS, 45 kg N ha^{-1} at 60 DAS, and 30 kg N ha^{-1} at 90 DAS. The field was surface-irrigated immediately after sowing.

Each tillage system had four weed control treatments: oxadiazon (0.75 kg a.i. ha^{-1}) applied at 2 DAS followed by fenoxaprop + ethoxysulfuron (0.045 kg a.i. ha^{-1}) applied at 28 DAS, oxadiazon (0.75 kg a.i. ha^{-1}) applied at 2 DAS followed by penoxsulam + cyhalofop (0.072 kg a.i. ha^{-1}) applied at 28 DAS, control (one hand-weeding), and weed-free. In the weed-free plots, weeds were removed by hand every week until 70 DAS. In the other three weed control treatments, a hand weeding was performed at 42 DAS, including in the control plots, where weeds were allowed to grow before and after the hand weeding. In completely weedy plots, yield losses in dry-seeded rice systems are greater than 90% (Chauhan and Johnson, 2011b). In addition, it is not common for farmers to leave their rice fields infested with weeds in irrigated areas. The herbicides were applied with a knapsack sprayer that delivered around 320 L ha^{-1} spray solution through flat fan nozzles at a spray pressure of 140 kPa. In both seasons, the area of each subplot was 44 m^2 (10.0 m × 4.4 m). The experiments in both seasons were arranged in a split-plot design, with tillage system as the main plots and weed control methods as the subplots. There were four replications in each season, but one replication in the WS11 had very poor crop emergence due to prolonged standing water after crop sowing. Therefore, data from only three replications were used in the WS11.

2.2. Effect of tillage systems on weed seedling emergence pattern

In the control plots of each tillage system, two quadrats of 20 cm × 20 cm were prepared immediately after crop sowing. In these quadrats, seedling emergence of important weed species was recorded at 7, 14, 21, 28, and 35 DAS and expressed as plants m^{-2}.

2.3. Effect of tillage systems and herbicides on weed density, weed biomass, and grain yield

The efficacy of herbicides on different weeds was evaluated at 26 DAS (2 days before the spray of post-emergence herbicides) and 42 DAS (14 d after the spray of the post-emergence herbicides and before the hand weeding). At each sampling time, two quadrats of 40 cm × 40 cm were placed in each plot at random to determine the density and biomass of different weeds. At crop harvest, only total weed biomass was determined from the same number and size of quadrats. Biomass was determined after drying the samples at 70 °C for 48 h. The crop was harvested in the last week of October 2011 and first week of May 2012. The harvested area for grain yield was 24 m^2 in WS11 and 10 m^2 in DS12. Grain yield was converted to t ha^{-1} at 14% moisture content.

2.4. Statistical analyses

Data were analyzed using ANOVA to evaluate differences between treatments, and the means were separated using LSD at $P = 0.05$ (GenStat 8.0, 2005). Weed density data were square-root transformed ($\sqrt{x + 0.5}$) due to high variance, whereas transformation did not improve the homogeneity of weed biomass and grain yield data. The data on weed seedling emergence pattern in the control plots were presented using standard error of means.

3. Results

3.1. Effect of tillage systems on weed seedling emergence pattern

The experimental plots contained many weed species: *Cyperus iria*, *C. rotundus*, *D. ciliaris*, *E. colona*, *E. indica*, *E. prostrata*, *Ludwigia octovalvis*, *P. oleracea*, *Trianthema portulacastrum*, *Dactyloctenium aegyptium*, *Murdannia nudiflora*, *Lindernia anagallis*, *Boerhavia*